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Fisheries:

History, Science, and Management

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Fisheries Management

The overall goal of fisheries management is to produce sustainable biological, social, and economic benefits from renewable aquatic resources. Fisheries are classified as *renewable* because the organisms of interest (*e.g.*, fish, shellfish, reptiles, amphibians, and marine mammals) usually produce an annual biological surplus that, with judicious management, can be harvested without reducing future productivity. In contrast, *nonrenewable* resources (*e.g.*, oil, coal, iron, and copper) are available in fixed quantities and not replaced except over geologic time.

The benefits humans gain from a fishery are diverse and may be enumerated in several ways. Most commonly, benefits are computed as *commodity* output — the weight or number of fish produced. Commodity output may be further split between the animals harvested by capture (fishing for wild animals) or culture (produced as captive animals) — commonly called the *capture* fisheries and the *culture* fisheries, respectively.

Benefits are also commonly measured as wholesale or retail economic *value* of the commodity output. Such benefits are easily calculated for *commercial* fisheries because the products are usually sold, but for sport or *recreational* fisheries, the quality of the fishing experience is very important, so measures of catch in weight, number, or value only partially measure the benefits provided to fishermen or to society. Measurements of the indirect economic value of recreational fishing that include the quality of the fishing *experience*, however, remain controversial. Even in commercial or subsistence fisheries, substantial benefits may be associated with *cultural* or *religious* aspects. Although such benefits are difficult to measure, they may be very important to the participants.

Beyond the direct benefits derived from harvested fish or the fishing experience, benefits are also derived by individuals and society from simply *knowing* that a particular natural resource exists (often called *existence* value). Society and individuals receive intangible benefits from preserving species and habitats, especially those in danger of extinction. Such benefits are often significant, but, like the benefits from recreational fishing, they are also exceedingly difficult to quantify in economic terms. The whale fishery is an example for which the value of leaving the animals unharvested currently is of greater benefit (primarily intangible) in most societies than the value (economic) of the harvested animals.

Whether measurable or not, fisheries management is increasingly being guided by ecological benefits mandated in treaties, laws, and government policies. For example, the *Convention on Biological Diversity* obligates signatory nations to preserve their biological diversity to the maximum possible extent. Many nations also have laws to protect species at risk of extinction and these laws may be important constraints on the scope, type, and intensity of fishing that will be permitted.

In practice, the over-arching management policy goal for managing a nation's fisheries is often stated in general terms such as:

> *"To ensure the attainment and continued satisfaction of human needs for present and future generations in an environmentally non-degrading, technically appropriate, economically viable, and socially acceptable manner, and such that land, water, plant, animal, and genetic resources are maintained."*

The challenge for the fisheries manager is to translate such a general policy goal into a practical, effective program to maximize benefits of specific fisheries to society.

Fish vs. Fisheries

The words "fish" and "fisheries" have several meanings and these terms often cause confusion. As traditionally used in fisheries management, *fish* typically includes the entire suite of *aquatic* organisms that are harvested (*e.g.*, mackerel, tilapia, tuna, guppies, sea turtles, seals, whales, sea urchins, clams, squid, and frogs), or *could* be harvested if their numbers permitted. Thus, the term *fish* is not solely the *fin fish* (*i.e.*, fish that have fins), so a fisheries manager may work with turtles, squid, or sponges, rather than fin fish. *Shellfish* (i.e., clams, crabs, lobsters) are also included under the broad definition of *fish*. In contrast to *fisheries* managers, *wildlife* managers generally deal with terrestrial mammals and birds (*e.g.*, deer, wolves, bears, ducks, hawks, and whooping cranes).

A *fishery* is defined generically as a system composed of three interacting components: the aquatic biota, the aquatic habitat, and the human users of these renewable natural resources. Each of these components influence how the fishery performs. Understanding the entire system and its parts is often essential to successful management of a fishery.

There are many different types of fisheries and they may be classified in several ways:

- **Type of environment** (*e.g.*, freshwater habitats — lakes, reservoirs, rivers, streams, and ponds; saltwater habitats — estuarine, coastal, and open ocean).

- **Method of harvest** (*e.g.*, seining, trolling, trawling, fly casting, spearing, and dip netting).

- **Type of access permitted** (*e.g.*, open access to fishing, open access with regulation, limited or purchased access, private property)

- **Organism of concern** (*e.g.*, salmon, shrimp, bass, turtles, squid, cod, sharks, sea horses, whales, and swordfish).

- **Purpose of fishing** (*e.g.*, commercial fishing for a product to sell, subsistence fishing for direct food consumption, or recreational fishing for sport and leisure).

- **Degree of wildness** of the target animals (*e.g.*, totally wild and free-roaming animals, totally captive animals grown in ponds, or animals spawned in captivity, but released in the wild to be captured when they mature).

History of the Human/Fish Relationship

Fish have occupied an important place in human society for thousands of years. Early humans obtained fin fish, shellfish, and other aquatic life along the shores of lakes, rivers, and oceans. Archeological records document use of fish spears 90,000 BP (90,000 years before present), nets 40,000 BP, and fish hooks 35,000 BP. The earliest documented human communities dependent on fishing occurred in the vicinity of Lake Mungo (Australia) 30,000 BP and Crete 8,000 BP. The Egyptian aristocracy fished as a leisure activity at least 4,000 BP. Fish have been raised in captivity for several thousand years.

With the development of better preservation techniques (*e.g.*, drying, smoking, and salting) and improved transportation, in the Middle Ages *commercial* fishing began shifting from local, small-scale activities to commercial, large-scale enterprises. Boat design and construction advanced, along with corresponding improvements in fishing gear and preservation techniques, especially the advent of canning. Canning represented a particularly important advancement because it permitted long-term storage and large-scale distribution of fisheries products.

Cod fishing off eastern North America began in earnest in the early 1500s. By the 1600s, whaling was a prominent activity in many high seas locations. In the late 1800s steam-power ships, along with mechanized fishing techniques and refrigeration, enabled development of the large-scale industrial fisheries that still exist today. Over the past 100 years, the global level of fishing has expanded continuously, a trend disrupted only briefly during the two world wars. After World War II, the intensity of commercial fishing especially increased.

Today, commercial fishing continues to be a major economic sector in many countries. In addition to the large worldwide value of the catch, approximately 36 million people (15 million full-time, 13 million part-time, and 8 million occasional) are employed in the capture and culture fisheries.

Although documented for thousands of years, *recreational* fishing only relatively recently has become an activity enjoyed by large numbers of people. The sport surfaced during the Renaissance as a socially acceptable leisure activity and received broad visibility with the 1653 publication of *The Compleat Angler* by Izaak Walton. By the mid 1800s, recreational fishing was an important and common activity, particularly in North America and Europe. The scale of recreational fishing greatly expanded after World War II, especially in North America.

Millions of people fish recreationally and they support a multi-billion-dollar sport fishing industry worldwide (*e.g.*, fishing gear and equipment, bait, boats, motors, outdoor clothing, lodging, and food). Recreational angling ranges in extremes from the serenity of fly-fishing in a remote alpine stream, to the noise and excitement of a bass fishing tournament held in a large reservoir, to the excitement of a child catching his first fish from the bank of a pond.

Beyond the widespread pursuit of wild fish for commercial or recreational purposes, many aquatic species are now successfully raised in aquaculture facilities. Raising fish in captivity (especially various carp species) for food has been practiced in China for at least 4,000 years. The Chinese also developed effective means to breed and raise fish for ornamental purposes, an early precursor to today's vast aquarium market. By the mid 1900s, carp, tilapia, catfish, trout, salmon, and shrimp were widely raised for the *food* market, while several of these and other species such as pike, sunfish, bass, and walleye were raised for *stocking* to enhance recreational fishing opportunities.

Current Uses of Fisheries Resources

Over 4,000 species of aquatic animals are harvested worldwide, totaling approximately 120 million metric tons annually. The total harvest includes *capture* fisheries (*e.g.*, fish caught by nets, trawls, hooks, etc.) and *culture* fisheries (*e.g.*, fish grown in ponds, cages, hatcheries, etc.), generally called *aquaculture*. The harvest tonnage from *capture* fisheries quadrupled between 1950 and 1990, but has leveled off or even declined since 1990. Harvest from *aquaculture* continues to increase. Fisheries harvest data are often of questionable accuracy, but the most recently available data on the combined capture and culture harvest suggest that China is the world's leading fish producer (32.5%), followed by Japan (5.1%), India (4.5%), USA (4.4%), and Russia (3.9%).

Aquacultural production continues to increase in importance worldwide and now accounts for approximately one-fifth of the total fish produced. Atlantic salmon, cultured in cages and pens, are raised in Norway, Scotland, Chile, Canada, USA, and elsewhere and provide the retail market with fresh fish year around. Catfish, grown in ponds in the southern USA, and trout, grown in hatcheries in the northern USA, provide high quality, reliable, year-round products to the national retail market. Carp and tilapia are produced in large numbers, especially in Asia and Africa, and provide the primary source of animal protein for humans in those areas.

Worldwide annual per capita consumption of fish and shellfish is approximately 34 pounds (15 kg), but this varies considerably among regions and individual countries. Per capita consumption of fish has nearly doubled since the 1960s. Europeans and Asians tend to have the highest per capita consumption. Annual per capita consumption in the USA is approximately 15 pounds (7 kg), with tuna, shrimp, pollock, salmon, and catfish being the top five.

In North America, the economic vitality of some rural communities depends on catering to the needs of recreational fishermen (*e.g.*, fishing equipment, outdoor clothing, boats, motors, trailers, food, and lodging). In 1996, the estimated 35 million American adults (age 16 and older) who fished recreationally spent over US$37 billion for goods and services related to the sport. The indirect economic impact of this direct expenditure totaled over US$108 billion.

The market for aquarium and ornamental fish is important worldwide and continues to increase. Fish to supply this market are obtained from both wild and captive stocks. The live fish department is one of the most popular and profitable in many pet stores. Coupled with the sale of live fish, there is a market for aquaria, aquarium supplies, and, of course, fish food and medicine. Approximately 10 million ornamental *saltwater* fish are imported annually throughout the world. The number of *freshwater* fish imported is much higher, and includes more than 5,000 species worldwide. The value of the USA retail ornamental fish market (live animals for aquaria and ornamental ponds only) is approximately US$3 billion.

Characteristics of Aquatic Environments

Lakes, streams, ponds, oceans, and estuaries are biologically productive, but their productivity has ecological constraints and these constraints can be reduced by human actions. Many aquatic habitats have been altered by human actions (dredging, filling, damming, road building, pollution, and introduction of non-indigenous species) and their potential for producing sustained fish harvests have been reduced.

Variability is a pervasive characteristic of all ecosystems. Even with the total absence of human activity, aquatic ecosystems exhibit considerable fluctuations in the abundance of individual species. Fish species may vary in abundance several fold between years. In some years there may be tremendous spawning success. In other years the same species may have little or no reproduction. Variability in the aquatic environment makes it challenging to assess the likely biological consequences of fisheries management options such as adjusting harvest levels, changing gear regulations, or even placing a moratorium on fishing.

Climatic changes also alter the productive capacity of aquatic environments over the long-term. Subtle shifts in ocean currents may cause some fish populations to collapse and others to thrive. Some changes in fish abundance caused by climatic or ocean shifts may happen over centuries and are not apparent without data sets of a century or more. Droughts, so apparent in their ecological effect on the terrestrial landscape, are also important to the aquatic environment, but their effects are usually much less visible. Major regional droughts, for example, are often correlated with increased upwelling of deeper, nutrient-rich ocean waters which stimulate increases in fish production. Even in the absence of all human activity, climate shifts cause the size of salmon runs to vary year-to-year and decade-to-decade.

Evolution of Fisheries Management Concepts

The history of fisheries management reflects the conventional wisdom of the day. Over the past two centuries, the level of ecological understanding has greatly increased. Prior to the 1800s, most people presumed that biological resources from inland and marine waters were inexhaustible given the level of harvest possible by the modest number of people who fished and the limited effectiveness of their fishing gear.

By the mid 1800s, the idea of unlimited natural riches from inland waters and the ocean was no longer credible. One popular approach to overcoming Nature's constraints on sustainable harvest was to apply *animal husbandry* concepts, including the idea that "seeding nature" with fish produced in captivity would permit much greater levels of fishing to occur. Conventional wisdom held that *aquaculture* could produce a nearly unlimited supply of fish of superior quality and according to a predictable schedule, just as farmers had long achieved with domestic livestock. In captivity, fish could be fed a high quality diet, protected from predation, and the quality of the product improved by selective breeding. If aquaculture performed as hoped, fisheries managers would no longer have to depend on the vagaries and limitations of nature for fisheries products.

For many species in many situations, aquaculture has worked well. Culture techniques greatly improved in the late 1800s. Selective breeding created animals better adapted to life in captivity. However, the expectation that aquaculture would be a solution to Nature's limitations was not fully realized.

By the early 1900s, the limitations of aquaculture as a tool to supplement or replace wild fish were being recognized and *harvest regulation* was thought to be the more effective way to assure sustained harvests. However, because the scientific underpinning for many harvest regulations were poor and public pressure to continue heavy fishing was great, regulations were often modest, poorly enforced, and produced disappointing results in limited harvest to sustainable levels.

Coupled with increased recognition of the need for regulations to control over-fishing, an appreciation emerged that *habitat* was a limiting factor in fish yields, especially in inland and coastal waters. Thus, stream, lake, and estuarine habitat improvement efforts became more common throughout North America and continues today.

By the mid 1900s, *scientific* fisheries management was the dominant paradigm. The idea underlying this approach was that every fish population had the potential to produce a harvestable surplus and the largest surplus that could be harvested annually from that population (*maximum sustainable yield*) could be estimated by rigorous scientific analysis (*i.e.*, stock assessment). The job of the fisheries manager was to control fishing pressure, using various regulations, at a level such that sustainable catch levels could be achieved in perpetuity. However, fishing pressure, as always, was very difficult to control and many fisheries ended up being over-harvested and yields eventually declined.

In the 1970s, the concept of *optimum sustainable yield* became popular, primarily in response to concerns that efforts to maximize the catch in recreational fisheries management overlooked, or at least under valued, many important benefits received by fishermen and society. Less commonly, it was also used in managing commercial fisheries. Management goals using this approach tended to weigh more heavily the *quality* of the fishing *experience* or the *socio-economic* aspects of fishing, and place less emphasis on the actual catch. Maximum benefits to society were usually achieved at catch levels *below* maximum sustainable yield.

By the late 1900s, the trend in recreational fisheries management was toward *species* and *habitat* protection, especially for inland and coastal waters. The widespread recognition that some aquatic species were at risk of extinction led to public pressure to reverse such trends. The main causes of the decline of fish species was habitat alteration and introduction of non-native fish species. Only rarely was over-fishing the primary cause of precipitous declines in fish abundance. In fact, most endangered fish species have never been fished. "Endangered species" and "species at risk" legislation directed government agencies and fisheries managers to emphasize protecting species above catch. Under such legislation, fishing may be permitted only if it does not jeopardize legally protected species.

A recent trend in recreational and commercial fisheries management has been the emergence of the *stakeholder approach*. A stakeholder is any citizen or group potentially affected by, or having a vested interest in, an issue, program, action, or decision. The idea behind involving stakeholders in fisheries management is that society has a wide range of conflicting views on what fisheries management goals should be; therefore it is desirable to include input from the full range of stakeholders in the process of defining goals and selecting management measures. Fisheries management plans developed with stakeholder involvement are assumed, therefore, to have a higher likelihood of garnering widespread support.

Co-management represents a further development of the stakeholder approach where some of the authority to manage the fishery is vested in the fishermen themselves or organizations such as Indian or tribal government. There are many current and proposed variants of co-management, but they all transfer a degree of regulatory authority from government fisheries agencies to fishermen, associations, or other organizations. In some fisheries a market is created for individual, transferable, fishing rights. In such situations the right to fish may be purchased in an open market.

A widely accepted development in fisheries management has been the *precautionary principle*. The basic concept is that decision-makers (*e.g.*, fisheries managers) ought to err on the side of caution in managing natural resources. Often the scientific basis for fisheries management decisions contains considerable uncertainty. Given the highly unpredictable future environmental and social conditions, it is wise for managers to use caution in managing fisheries.

Lake Fisheries Management

Lakes (including reservoirs formed by man-made dams) vary from large (*e.g.*, Great Lakes, Caspian Sea) to small (*e.g.*, farm ponds, minuscule alpine pools).

Maintaining at least reasonable good water and habitat quality is absolutely essential to nourishing healthy fish populations. Pollution control and abatement, while typically outside the direct purview of fisheries managers, are essential if management goals are to be achieved.

For large lakes, fisheries management involves primarily assessing, then selecting, fishing or harvest levels that are sustainable. Other management techniques include *intentional* introduction of non-native species (*e.g.*, Pacific salmon to the Great Lakes), or control of *unintentional* and undesirable introductions (*e.g.*, sea lampreys in the Great Lakes).

There are more management options for small lakes and reservoirs. Small lakes may be manipulated by altering water levels or habitats (*e.g.*, improving spawning areas, adding brush piles to provide hiding places for fish) or altering water quality (e.g., fertilizing low nutrient lakes, reducing the flow of nutrients into lakes with excessive nutrients) to increase the productivity of desirable species. In some circumstances, improving access to the lake may promote greater use by fishermen. In extreme cases, small lakes may be *chemically rehabilitated* (*e.g.*, all fish are removed by complete poisoning and a desirable mix of fish species reintroduced). Regulation of lake fishing usually involves limits on the *catch* (*i.e.*, species, number, and size that may be kept), *time* (*i.e.*, season and hours when fishing is permissible), and *gear* (*i.e.*, type of fishing equipment and bait that may be used).

Reservoirs often present additional challenges to fisheries managers because they are built for other primary purposes (*e.g.*, flood control, electricity generation, irrigation, water storage, transportation), and these uses often conflict with secondary purposes, such as achieving fisheries benefits for society. Water level fluctuations in many reservoirs, both daily and seasonally, which often result from electricity generation, flood control, and irrigation practices, and have profound consequences for reservoir fish populations. In practice, fisheries managers must work collaboratively with many other groups to achieve a mix of societal benefits. Only a few of the benefits from most reservoirs are associated with fish, fishing, and environmental quality.

Management of many small lakes tends to be the responsibility of a single governmental or nongovernmental entity, greatly simplifying fisheries management. Large lakes, on the other hand, tend to exhibit more complex management involving multiple agencies. Such interjurisdictional decision-making greatly compounds fisheries management problems. For example, with five nations surrounding the Caspian Sea, managing the sturgeon fishery (which produces highly valued caviar) sustainably has been difficult because of the lack of a single, enforceable management plan. As a result, Caspian Sea sturgeon populations have dropped 90% over the past several decades.

Riverine Fisheries Management

Riverine systems describe a continuum of aquatic systems ranging from small creeks a few miles in length to rivers the size of the Amazon, Mississippi, McKenzie, Yukon, and Columbia. One important characteristic is that many riverine systems pass through, or form the boundaries between, different political jurisdictions. Multiple political and management jurisdictions often result in unsatisfactory management of riverine fisheries when agencies fail to cooperate toward achieving common societal goals.

Rivers, especially larger ones, commonly undergo extensive habitat alteration resulting from human activities such as building dams, dikes, bridges, shipping channels, and waste treatment plants. Also, because of dikes and other structures, it is common to lose the connections between rivers and their productive flood plain channels and backwaters, habitats that often provide essential spawning and nursery areas for fish. In many cases, fisheries managers must work with highly altered ecosystems that are no longer suited for the fish species most valued by the public.

Harvest regulations are important in river fisheries, but habitat protection and improvement are especially important. Many rivers, both large and small, are severely polluted or altered by domestic, farm, and industrial waste, agricultural and urban runoff, water withdrawal for domestic, agricultural, and industrial use, siltation, and riparian (stream-side) alterations. Poor water quality caused by pollution and lack of habitat diversity are often the limiting factors in developing successful fisheries management programs in rivers. The effects of pollution may be very subtle and indirect. Certain pollutants, for example, may make fish more vulnerable to predation by slightly reducing their ability to sense the presence of a predator.

Unlike lakes, streams and rivers are flowing systems that have a notable self-cleansing ability. Rapid turnover of water can lead to faster recovery of water quality than occurs in lakes or wetlands, where nutrients and pollutants may remain trapped in sediments for many years. However, the lower, coastal sections of rivers are often slow-moving and are often a long-term repository for contaminants.

Habitat alterations that adversely affect fish are common in riverine systems. The Colorado River of the southwestern USA, for example, is subject to numerous flow diversions and is reduced to a mere trickle by the time it reaches the Gulf of California. The Columbia River and its tributaries, arguably the most regulated river system in the world, contain 250 “large” dams and several thousand “small” ones. Such highly altered habitats no longer favor native fish species, many of which are migratory. Under these altered habitat conditions, certain non-native fish species may prosper, while many native species are reduced in number or even extirpated.

Small riverine systems (*i.e.*, streams, brooks, and creeks) are especially vulnerable to over-fishing, habitat destruction, and the effects of land-use practices such as farming and urbanization. In extreme cases, management may include prohibition of fishing or, at least, highly restrictive fishing regulations. At the other extreme, some large riverine systems, especially in their lower reaches, may be managed similarly to large lakes and coastal fisheries.

Commercial fishing may be the dominant type of fishing in many large rivers, especially in tropical areas.

Coastal Fisheries Management

The marine environment immediately adjacent to land supports *coastal fisheries* and includes near shore marine, estuarine, and intertidal ecosystems. An *estuary* is a coastal water body that has a free connection to the ocean, and alternately with the tides, exhibits characteristics of both fresh- and saltwater environments. Because marine biota move into coastal rivers, the lower, intertidal reaches of rivers are often included as coastal fisheries. Intertidal environments are particularly important as nursery areas for the juveniles of many valuable saltwater fish species.

Coastal fisheries present an array of challenges to the fisheries manager. Human population density tends to be higher along the coasts, and this means that aquatic coastal habitat is likely to be substantially altered (*e.g.*, sea walls, dredging, draining, and buildings) or polluted (*e.g.*, from municipal and industrial waste, ship discharge, and runoff). One of the greatest challenges in managing coastal fisheries is the loss of coastal wetlands. These wetlands provide habitat for many adult fish and shellfish, and are also essential breeding and rearing areas.

Coastal fisheries are also often heavily harvested and tend to experience serious conflicts among user groups. Surf fishermen, crabbers, shrimp trawlers, oil extractors, shippers, boaters, swimmers, and sightseers all utilize the coastal environment in ways that often conflict with each other. Use can be intensive. There are more than 9 million salt water recreational anglers in the USA.

A major change in coastal fisheries management began in the 1970s as some nations extended their off-shore management jurisdiction in an attempt to control fishing by foreign nations. In 1982, most nations adopted the United Nations *Law of the Sea Convention*, which recognized the 200-mile line as separating the high seas from waters in the *exclusive economic zone* of the adjacent nation. If desired, individual nations could extend their exclusive economic zone to 200 miles under international law. The United States did so in 1983. In spite of the Law of the Sea Convention, overall fishing pressure has generally remained heavy, especially in exclusive economic zones, because foreign fleets were soon replaced with domestic ones.

Open Ocean or High Seas Fisheries Management

Open ocean fisheries are those that operate away from the coasts and often outside of any nation's territorial waters. The two general categories of fish that are targeted in such fisheries are the *pelagic*, or open-water-dwelling, fishes, and the *demersa*l, or bottom-dwelling, fishes. Pelagic fish species tend to feed and travel near the ocean surface. Demersal fish species tend to live on the continental shelves closer to shore. Tuna and swordfish are examples of commercially important pelagic species, while cod, hake, flounder, and toothfish are important demersal species.

The inadvertent capture of non-target species (called *by-catch*) is a serious management challenge in many fisheries, but especially for open ocean and coastal fisheries. Perhaps a third (sometimes much more) of the catch is discarded by fishermen as not marketable. Bycatch may be the young of valued sport or commercial fish species or important food sources for sport or commercial fish species. Shrimp trawlers, for example, catch and discard large quantities of small fish while pursuing the much more valuable shrimp. Various types of fishing gear used by commercial fishermen can injure, and often kill, protected animals such as seabirds, marine mammals, and sea turtles. For example, the indirect catch of dolphins in tuna fishing has led to consumer boycotts and a demand for "dolphin-safe" tuna products. Likewise, devices that effectively exclude turtles from capture have been incorporated into the trawls used by commercial shrimp fishermen.

Habitat alteration caused by certain fishing gear is also a concern in some locations. Trawling (trawls are large, heavy nets dragged by fishing boats) may alter the physical and biological characteristics of the sea bed, in particular sea grass beds and coral reefs, in ways detrimental to the well-being of target fish populations. Thus, fisheries managers may have to balance how to minimize the habitat alteration of sea floors caused by trawls while still permitting the capture of the target species.

Serial depletion of fish populations is another challenge to managers of open ocean fisheries. Typically, this means that fishermen move to new fishing grounds as the ones closer to home are depleted. A related type of serial depletion is that caused by the development and use of improved fishing gear that allows fishermen to exploit new fishing grounds as the old ones are depleted. A recent trend has been for open ocean fishermen to move into fishing more deep water environments as more accessible near shore stocks decline.

Open ocean fisheries management is currently in a state of flux with intense international efforts to make them economically and ecologically viable within a framework of producing sustainable, but profitable catches. For example, one challenge for fisheries managers is the heavy subsidies many nations provide to commercial fishermen which creates *excess fishing capacity*. In many cases fishing would not otherwise be profitable, but subsidies in the form of tax incentives or cash payments make it cost effective for fishermen to continue fishing. Thus, in many cases the laws of supply and demand that would tend to prevent over-fishing do not come into play.

Diadromous Fisheries Management

Diadromous fishes are those characterized by a life cycle of either spawning in freshwater environments and spending their adulthood in marine environments (*anadromous* species) or spawning in marine environments and spending adulthood in freshwater environments (*catadromous* species). Diadromous fisheries represent unique challenges to fisheries managers because target species often cross multiple jurisdictions. Unless management efforts are well coordinated, the combined effect of decisions by different jurisdictions can result in serious depletion of these resources.

Anadromous fish (e.g., salmon, American shad, striped bass, smelt, and sturgeon) are important species commercially and recreationally. Many rivers no longer support major spawning runs of anadromous fish.

Until the 1800s, large runs of Atlantic salmon were found in many coastal rivers of both western Europe and eastern North America. By the middle to late 1800s, salmon runs in the eastern USA and western Europe had been drastically reduced by the effects of over-fishing, dams, and pollution. Overall, runs continue to be much reduced on both sides of the Atlantic. The largest remaining runs, although small by historic standards, occur in eastern Canada, Iceland, Ireland, Scotland, and the northern rivers of Norway. Aquaculture has largely replaced harvested wild fish as the source of Atlantic salmon for the retail market.

The seven species of Pacific salmon, found on both sides of the North Pacific, also have, overall, declined significantly from historic levels, but not as dramatically as Atlantic salmon. Hatchery production has been used to maintain some runs in the southern region of the range (*e.g.*, Japan, Korea, California, Oregon, and Washington). In California, Oregon, Washington, Idaho, and southern British Columbia, runs have been depleted by past over-fishing, dam construction, water withdrawal for irrigation, competition with hatchery-produced salmon, competition with various non-indigenous fish species, predation by marine mammals and birds, and climatic and oceanic shifts. Runs in the northern half of the range (*e.g.*, Russian Far East, Alaska, Yukon, and northern British Columbia) are in much better condition. The northern runs have been abundant for the past several decades, but will likely decline somewhat for several decades because ocean conditions in the North Pacific tend to shift on such a several-decade time cycle.

Striped bass, native to the East and Gulf coasts of North America, have been introduced to the Pacific Coast and are now found from Baja California to British Columbia. Overall, the species in its original range is less abundant than it was historically, but, never-the-less, catches are still substantial. Some runs on the west coast of North America do very well. The causes of the decline in its original range are similar to those that precipitated the drastic declines in salmon runs (*i.e.*, dams, water diversions, pollution problems, and over-fishing).

American shad are found from the Gulf of Mexico up the Atlantic coast and as far north as New Brunswick. Generally, in their native range, shad runs are much reduced from historic times due to dams, pollution, and over-fishing. American shad have been introduced to the west coast of North America and have done well in some rivers, especially the Columbia and Sacramento-San Joaquin.

Several species of anadromous sturgeon are also of particular concern. Some are highly prized for their roe (eggs often sold as caviar) and must be carefully managed to avoid over-fishing. Other sturgeon species are at risk of extinction and drastic national and international measures may be required to protect these species.

Many other species have anadromous forms (*e.g.*, smelt, alewife, blueback herring, and cutthroat, rainbow, brown, and brook trout) that support substantial fisheries in certain locations. In other locations, they are important in fisheries management because they are at risk of local extinction. Like salmon, all of these anadromous fishes are extremely vulnerable to dams and other impediments to migration; they are also sensitive to water diversions and pollutants.

A few species, such as American eels, are *catadromous* — they spawn in the ocean, but live their adult lives in freshwater. Eels are important commercial species in certain regions. They occur in rivers, lakes, estuaries, coastal areas, and open ocean. Their distribution ranges from the southern tip of Greenland, along the coast of North America, the Great Lakes, the Gulf of Mexico, the Carribean, and as far south as northern South America. Most of the catch is exported to Europe and Asia.

Aquaculture

Aquaculture continues to expand its importance in both commercial and recreational fisheries management. The growth of aquaculture has been especially rapid during the past decade.

Food production is the most common objective in aquaculture. Commonly raised species are carp, Atlantic salmon, rainbow trout, catfish, tilapia, shrimp, oysters, mussels, and seaweed. Currently, one-third of the total world food fish supply is obtained from aquaculture and this portion is increasing. The amount of farmed fish produced worldwide has more than doubled since 1989.

Producing fish in captivity for subsequent stocking to enhance, maintain, or initiate fishing is also important, especially in North America. Trout are commonly raised in USA and Canada to support fisheries subject to intensive recreational fishing, the so-called "put-and-take" fisheries. On the Pacific coasts of North America and Asia, commercial enterprises operate hatcheries to artificially maintain runs of salmon to meet market demand, a practice called *ocean ranching*. After being hatched and reared from eggs, juvenile salmon are released to migrate to the ocean, spend several years growing to adult size, then return to the hatchery of origin to spawn. At the hatchery, they are captured and some are then spawned artificially to obtain eggs for the next generation. The rest are processed for market.

A fairly recent development in fisheries management, *conservation aquaculture*, is using aquacultural techniques to produce fish threatened with extinction. These "captive breeding" efforts may be the only hope of preserving or recovering certain fish species or populations when natural reproduction is compromised.

Species and Habitat Preservation

By the 1990s, management objectives for many freshwater fisheries in North America had shifted from optimizing commodity output to protecting habitat or preserving imperiled species. Concerns about loss of *biological diversity* and *biological heritage* often eclipsed concerns for sustaining commercial or recreational catches. This was especially true for the Pacific coast salmon fisheries and fisheries in more remote, pristine areas such as national parks and wilderness areas.

Overall, alteration of aquatic habitat (*e.g.*, dam construction, flood control structures, dredging to facilitate water transportation, filling to create useable land, sediment and pollution runoff, acid rain, and many others) is one important cause of the tenuous status of many fish species. Thus, protecting fish *habitat* has become a prime focus of many fisheries management agencies.

Non-indigenous fish species (*i.e.*, those not native to the area) include both *exotic* species (*i.e.*, those from a foreign land) and *non-native* species (*i.e.*, those that have expanded beyond their native range) and they often adversely affect valued native fish populations. Non-indigenous species often compete with or prey upon commercially or recreationally important fish species. They may also hybridize with closely related native species and cause a distortion in the gene pool. Non-indigenous species have contributed to the decline of approximately two-thirds of the threatened or endangered fishes in the USA. Many non-indigenous fish introductions have been the result of intentionally releasing bait fish after a day's fishing, unintended releases from international shipping activities, and releases and escapes from the aquaculture and aquarium trades.

Not all non-indigenous fish species are perceived to be management problems. Many highly valued and heavily harvested fish species were intentionally introduced by fisheries managers and continue to enjoy widespread public support. Among the most widely introduced fish species in North America are Pacific salmon, rainbow, brown, and brook trout, striped bass, walleye, small- and large-mouth bass, and bluegill. Recent trends in fisheries management have been away from introducing fish outside their native range.

Legislation to protect species from extinction also has affected the management priorities of fisheries agencies. For example, the USA Marine Mammal Protection Act (1972) and the USA Endangered Species Act (1973) are now the legal drivers for management of some fisheries (*e.g.*, over much of the range of Pacific salmon in the USA, the primary management goal is to prevent extinction, not to increase catch).

Internationally, the *Convention on Biological Diversity* (1992) imposes legal obligations on all signatory countries to conserve their biodiversity, manage their fisheries resources in a sustainable manner, and promote fair and equitable distribution of the benefits of each nation's genetic and biological resources.

Ecosystem Management

Beginning in the 1980s, a widespread view emerged that managing fisheries should be broadened in scope to include the entire ecosystem; hence the rise of *ecosystem management*. A precise, universally accepted definition of ecosystem management has yet to emerge, but it is generally seen as the application of ecological, economic, and social information, options, and constraints to achieve desired social benefits within a defined geographic area and for a specified period.

Part of the appeal of ecosystem management is that it may better balance the suite of benefits (*e.g.*, food fish, recreational fish, preserving endangered species, and preserving ecosystems) that society values. To date, ecosystem management has been most commonly implemented in public forests in North America. Efforts are now under way to apply the same concept to large lakes and open ocean ecosystems.

Adaptive management, the process of improving management effectiveness by learning from the results of carefully designed decisions or experiments, is often included in ecosystem management frameworks. The philosophy underlying adaptive management is the recognition that the ecological consequences of many fisheries management decisions are too uncertain to predict with confidence. Therefore, management decisions ought to be tentative and used to learn how the ecosystem responds. The information derived from such decisions allows the manager to adapt future decisions to reflect what has been learned from past decisions.

Another trend in fisheries management, now commonly practiced in Europe, is using the river basin as the management unit. River basins, or watersheds, have long been used in water management and pollution abatement, but have only recently been adopted in fisheries management. River basins tend to be the preferred geographic level of fisheries management that international organizations use.

Future of Fisheries Management

In the future, fisheries management will continue to reflect the overall values and preferences of the society within which it operates. Fisheries managers will strive to produce sustainable benefits from renewable biological resources, but society's needs will continue to evolve, resulting in different, and often conflicting, management goals. Efforts to maintain or increase the catch are likely to be tempered by society's growing interest in protecting the environment and preserving imperiled species.

Fish and fishing will remain important factors in the daily lives of many people, but especially so in those areas where animal protein from agriculture is in relatively short supply. Overall, harvest pressure on most aquatic environments will continue to increase in concert with rising demand for animal protein for use as human and animal food and for recreation opportunities.

Harvest restrictions in many fisheries are likely to become more constraining as fisheries managers attempt to maintain sustainable yields and avoid fishery collapses. International trade in fisheries products will likely be scrutinized to a greater degree in response to perceived environmental damage caused by excessive or inappropriate fishing. To counter past over-fishing in the ocean, for example, there is likely to be increasing public pressure to create legally protected areas where fishing is forbidden (*e.g.*, fish parks, marine reserves, and marine sanctuaries).

Protecting fish habitat will continue to be a primary management goal in the future. There will be a continuing emphasis on protecting the environment in general and water quality in particular. The emphasis in enhancing water quality will likely shift from controlling specific sources of pollution to reducing pollution from large-scale run-off. Fisheries managers will increasingly be focusing on water quality enhancement and pollution abatement. Introduction of non-indigenous species and genetically altered fish will be of increasing concern to fisheries managers.

In the future, aquaculture will likely provide a larger percentage of the total worldwide production of fisheries products. Domestication, genetic selection, genetic engineering, and other technological developments are likely to be employed to enhance aquacultural production.

Further Reading

Arrignon, Jacques. 1999. *Management of Freshwater Fisheries*. Science Publishers, Inc., Enfield, New Hampshire, 582 pp.

Avault, James W. 1996. *Fundamentals of Aquaculture*. AVA Publishing Company, Inc., Baton Rouge, Louisiana, 889 pp.

Boon, P.J., P. Calow, and G. E. Petts. 1992. *River Conservation and Management*. John Wiley and Sons, New York, New York, 470 pp.

Boyd, Claude E., and Craig S. Tucker. 1998. *Pond Aquaculture Water Quality Management*. Kluwer Academic Publishers, Boston, Massachusetts, 700 pp.

Clay, Charles H. 1995. *Design of Fishways and Other Fish Facilities*. Lewis Publishers, Ann Arbor, Michigan, 248 pp.

Cowx, I. G. (Editor). 2000. *Management and Ecology of River Fisheries*. Fishing News Books, Ltd., Osney Mead, Oxford, United Kingdom, 444 pp.

Gullucci, Vincent F., Saul B. Saila, Daniel J. Gustafson, and Brian J. Rothschild (Editors). 1996. *Stock Assessment: Quantitative Methods and Applications for Small-Scale Fisheries*. Lewis Publishers, Inc., Boca Raton, Florida, 527 pp.

King, Michael. 1995. *Fisheries Biology: Assessment and Management*. Fishing News Books, Blackwell Sciences, Ltd., Osney Mead, Oxford, United Kingdom, 341 pp.

Kohler, Christopher C., and Wayne A. Hubert (Editors). 1999. *Inland Fisheries Management in North America*. (Second Edition). American Fisheries Society, Bethesda, Maryland, 718 pp.

Knudsen, E. Eric, Cleveland R. Steward, Donald D. MacDonald, Jack E. Williams, and Dudley W. Reiser. 2000. *Sustainable Fisheries Management: Pacific Salmon*. Lewis Publishers, Boca Raton, Florida, 724 pp.

Lichatowich, James A. 1999. *Salmon Without Rivers: a History of the Pacific Salmon Crisis*. Island Press, Washington, DC, 352 pp.

Murphy, Brian R., and David W. Willis (Editors). 1996. *Fisheries Techniques*. (Second Edition). American Fisheries Society, Bethesda, Maryland, 732 pp.

Quinn, Terrance J., and Richard B. Deriso. 1999. *Quantitative Fish Dynamics*. Oxford University Press, New York, New York, 542 pp.

Ross, Michael R. 1997. *Fisheries Conservation and Management*. Prentice Hall, Upper Saddle River, New Jersey, 374 pp.

Royce, William F. 1996. *Introduction to the Practice of Fishery Science*. (Revised Edition). Academic Press, San Diego, California, 448 pp.

Scalet, Charles G., Lester D. Flake, and David W. Willis. 1996. *Introduction to Wildlife and Fisheries: An Integrated Approach*. W. H. Freeman and Company, New York, New York, 512 pp.

Sigler, William F., and John W. Sigler. 1990. *Recreational Fisheries: Management, Theory, and Application*. University of Nevada Press, Reno, Nevada, 418 pp.

Templeton, Robin G. 1995. *Freshwater Fisheries Management*. Fishing News Books, Blackwell Scientific, Ltd., Osney Mead, Oxford, United Kingdom, 241 pp.

Welcomme, Robin L. 2001. *Inland Fisheries: Ecology and Management*. Fishing News Books, Blackwell Scientific, Ltd., Osney Mead, Oxford, United Kingdom, 358 pp.

Author's Biography

Dr. Robert T. Lackey, senior fisheries biologist at the U.S. Environmental Protection Agency's research laboratory in Corvallis, Oregon, is also courtesy professor of fisheries science and adjunct professor of political science at Oregon State University. Since his first fisheries job 40 years ago mucking out raceways in a Sierra Nevada trout hatchery, he has dealt with a range of natural resource issues from positions in government and academia. His professional work has involved all areas of natural resource management and the interface between science and public policy. He has written 100 scientific and technical journal articles. His current professional focus is providing policy-relevant science to help inform ongoing salmon policy discussions. Dr. Lackey also has long been active in natural resources education, having taught at five North American universities. He continues to regularly teach a graduate course in ecological policy at Oregon State University and was a 1999-2000 Fulbright Scholar at the University of Northern British Columbia. A Canadian by birth, Dr. Lackey holds a Doctor of Philosophy degree in Fisheries and Wildlife Science from Colorado State University, where he was selected as the 2001 Honored Alumnus from the College of Natural Resources. He is a Certified Fisheries Scientist and a Fellow in the American Institute of Fishery Research Biologists.

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